

**Cultural Procedures for Propagation of
Rooted Cuttings of Sitka Spruce, Western
Hemlock, and Douglas-fir in British Columbia**

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**Cultural Procedures for Propagation of
Rooted Cuttings of Sitka Spruce, Western
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**Bevin G. Wigmore
Jack H. Woods**

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ABSTRACT

The use of rooted cuttings is explored as a means of bulking-up genetically improved families of Sitka spruce, western hemlock, and Douglas-fir for reforestation. The number of propagules produced from a small quantity of seed can be multiplied by taking cuttings from seedling stock plants. All methods are developed for 1-year-old cutting production in containers for consistency with most operational seedling production in British Columbia. This report describes cultural techniques for growing stock plants and rooted cuttings of Sitka spruce, western hemlock, and Douglas-fir, based on 3 years of nursery research and observations. It is concluded that 1-year container cutting production is technically feasible for Sitka spruce and western hemlock, but plagiotropism problems could not be overcome for the production of 1-year-old cuttings of Douglas-fir. A discussion of plagiotropism is included.

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In British Columbia, cuttings are being considered as a means to bulk-up¹ genetically improved families of several species. While cuttings of yellow-cedar (*Chamaecyparis nootkatensis*) are used here to compensate for a sporadic seed supply, and to propagate elite clones (Russell et al. 1990), the use of cuttings as a tool to bulk-up selected families is a new approach to delivering genetic gain.

Cultural techniques have been developed for production of interior spruce cuttings (*Picea glauca* × *engelmannii*) (Russell and Ferguson 1990), and there is interest in applying similar technology to three coastal species. Tree improvement programs for Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) have identified families with improved growth (Woods et al. 1995). For Sitka spruce (*Picea sitchensis*), families with superior weevil resistance have recently been identified (King et al., submitted for publication).

It takes several years to establish a seed orchard and bring it to full-scale production, so there is often a long delay in the deployment of the latest advances in genetic gain. During this interim period, rooted cuttings could be used to bulk-up the small amount of available seed. If found to be cost-effective, they could be used on an ongoing basis to augment seedling production by bulking-up the most elite families for use on highly productive sites.

In this context, a 3-year program was initiated in 1995/96 by a committee representing industry and the British Columbia Ministry of Forests to develop cultural production techniques for containerized rooted cuttings of Douglas-fir, western hemlock, and Sitka spruce, and to transfer the technology to commercial nurseries. Most of the experiments in this program were carried out at the B.C. Ministry of Forests Cowichan Lake Research Station (CLRS) and the Nursery Extension Services (NES). Subsets of some trials were grown at commercial nurseries.

This report summarizes the results of 3 years of research into, and operational experience with, nursery production of stock plants and juvenile rooted cuttings of Douglas-fir, western hemlock, and Sitka spruce. Section 2 describes two existing programs that provided a starting point for experimentation. Section 3 is an overview of the production system used in this project. Sections 4 and 5 provide the detailed results and cultural recommendations for production of stock plants and rooted cuttings. Section 6 contains a discussion of *plagiotropism*, a growth habit that obstructs the production of containerized Douglas-fir cuttings. Section 7 looks at changes in the genetic make-up of cutting crops through the nursery process, and Section 8 discusses field trials established and/or assessed during this project.

While this report is not intended to be a step-by-step grower's manual, some cultural recommendations are included. These recommended procedures are based on the knowledge available at the time, and each nursery should adapt them to suit their own environment and growing style.

1 Bold type indicates that the term is defined in the Glossary.

Western hemlock has not been propagated vegetatively for reforestation prior to this project, but there are successful reforestation programs with Douglas-fir and Sitka spruce cuttings outside British Columbia.

2.1 Douglas-fir in the U.S. Pacific Northwest

Weyerhaeuser Company has developed a large Douglas-fir cutting program in Washington State and Oregon. Approximately 3 million rooted cuttings of Douglas-fir are set annually to bulk-up full-sib seed obtained through controlled pollination. One-year-old seedling stock plants are grown and a single harvest of cuttings is taken from these plants. The Douglas-fir stock plants are then discarded because of rapid loss of juvenility and yield (Ritchie 1991). The cuttings are set in a greenhouse and rooted using bottom heat and fog. They are then transplanted to a nursery bed in late summer where they are grown for another year (Ritchie 1993). The rooted cuttings are quite plagiotropic when first transplanted, but they assume upright growth during the second year while in the nursery bed.

Douglas-fir cuttings and seedlings of the same size and genetic background appear similar and perform comparably, both in the nursery and after 2 years in the field (Ritchie et al. 1992, 1993). After 5 years in the field, there are no differences in height growth between the seedlings and the cuttings, but the cuttings have slightly smaller diameters and fewer branches (G.A. Ritchie, Weyerhaeuser Company, pers. comm., 1999).

2.2 Sitka Spruce in the United Kingdom

Sitka spruce rooted cuttings are used in the United Kingdom to bulk-up full-sib seed from selected families. They are produced by both government and private nurseries. Sitka spruce cuttings have been used operationally there since the early 1980s; by the early 1990s, annual planting of this stocktype was about 1.5 million. Previously estimated demand for 5 million planting stock per year has not materialized, partly because of the cost of cuttings, which is two to three times greater than seedlings (Mason 1992).

Most of the Sitka spruce cuttings in the U.K. are produced via a system of two **serial propagation** cycles over 6 years, as described by Morgan and Mason (1993). Most cuttings are produced as bareroot transplants. The original stock plants are grown in a greenhouse for 2 years from seed, then cuttings taken from these plants are rooted under mist. The rooted cuttings are transplanted to a nursery bed for an additional 1.5 years, after which they are used as stock plants for another round of propagation. This method results in a final bulking factor of 600 plantable trees per seed sown. Efforts to reduce production costs have resulted in some alternative methods being used, including hedging of potted stock plants for up to 6 years, and production of containerized cuttings for use on weed-free sites (Morgan and Mason 1993).

There are numerous reports from the U.K. that juvenile rooted cuttings of Sitka spruce grow as well as seedlings in the field, the only caveat being a possible loss of vigour in serially propagated cuttings (Baldwin and Mason 1986; Mason et al. 1986; Mason and Sharpe 1992).

3 OVERVIEW OF CULTURAL PROCEDURES USED IN THIS PROJECT

The nursery production system used in this project was a 2-year cycle, with stock plants grown in year 1 and rooted cuttings produced in year 2. The steps are summarized in Figure 1. This procedure was adapted from *Production of Genetically Improved Stecklings of Interior Spruce: A Grower's Manual* (Russell and Ferguson 1990).

Stock plants were produced annually from seed. The objective of stock plant production was to create as many healthy branches as possible. Small lots of elite seed were sown in January, then the seedlings were potted up in late May or June. Cultural techniques were used to encourage branching and growth throughout the spring and summer. The plants were allowed to go into dormancy in the fall, with late September appearing to be the optimal time for dormancy induction. By winter the potential cuttings were semi-lignified and ready for harvesting.

The objective of cutting production was to produce plantable rooted cuttings that were ready for lifting at the appropriate time of year and that met seedling specifications for size and quality. Cuttings were taken from December through March and rooted in Styroblocks^{TM2} with bottom heat and mist. After several weeks, the cuttings were weaned off the misting regime and put onto a normal seedling growing regime. Sitka spruce and western hemlock cuttings were lifted as a 1+0 stocktype, but Douglas-fir cuttings required transplanting to produce acceptable stem form.

4 STOCK PLANT PRODUCTION

4.1 Rationale

It is well known that both the rooting success and the growth rate of rooted cuttings decrease with the increasing maturity of the stock plant (Hackett 1988; Power et al. 1988). The occurrence and severity of plagiotropism increases with the age of the parent material as well. Use of juvenile stock plants is generally necessary to obtain an acceptable level of rooting and growth for an operational reforestation program.

To avoid stock plant maturation, 1-year-old seedling donors were produced on an annual basis for this project, and cuttings were harvested only once from each crop of stock plants. This was the technique developed by the B.C. Ministry of Forests for interior spruce (Russell and Ferguson 1990) and by Weyerhaeuser for Douglas-fir (Ross 1975). With Sitka spruce, serial propagation and the use of 2-year-old stock plants were also considered.

The three methods used to maintain juvenility of coniferous stock plants are **hedging**, **serial propagation**, and **tissue culture techniques** such as **somatic embryogenesis**. Hedging and serial propagation are used successfully with some species, such as radiata pine, black spruce, and yellow-cedar; but others, including Douglas-fir, do not respond well to this technique (Ritchie 1991).

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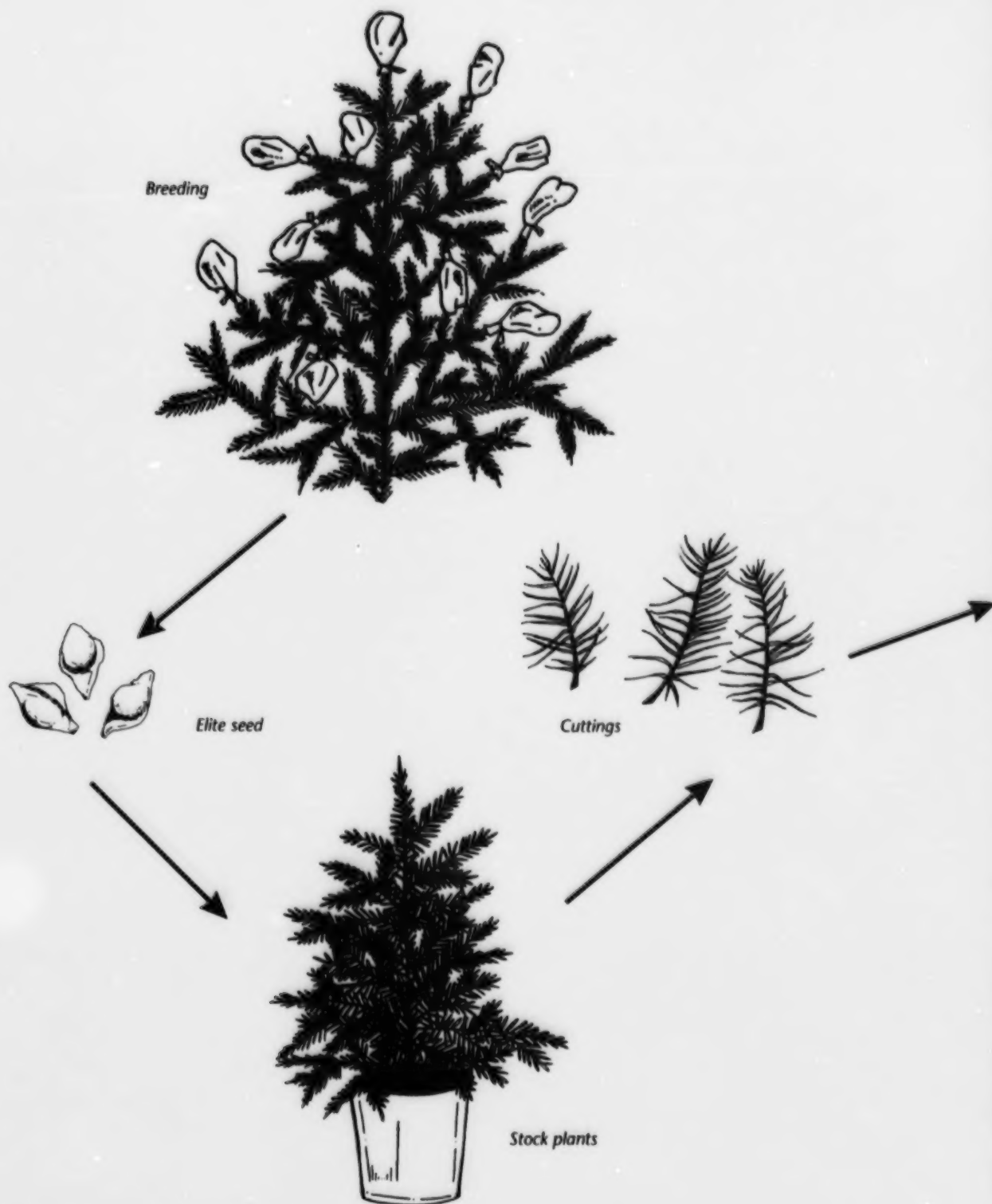
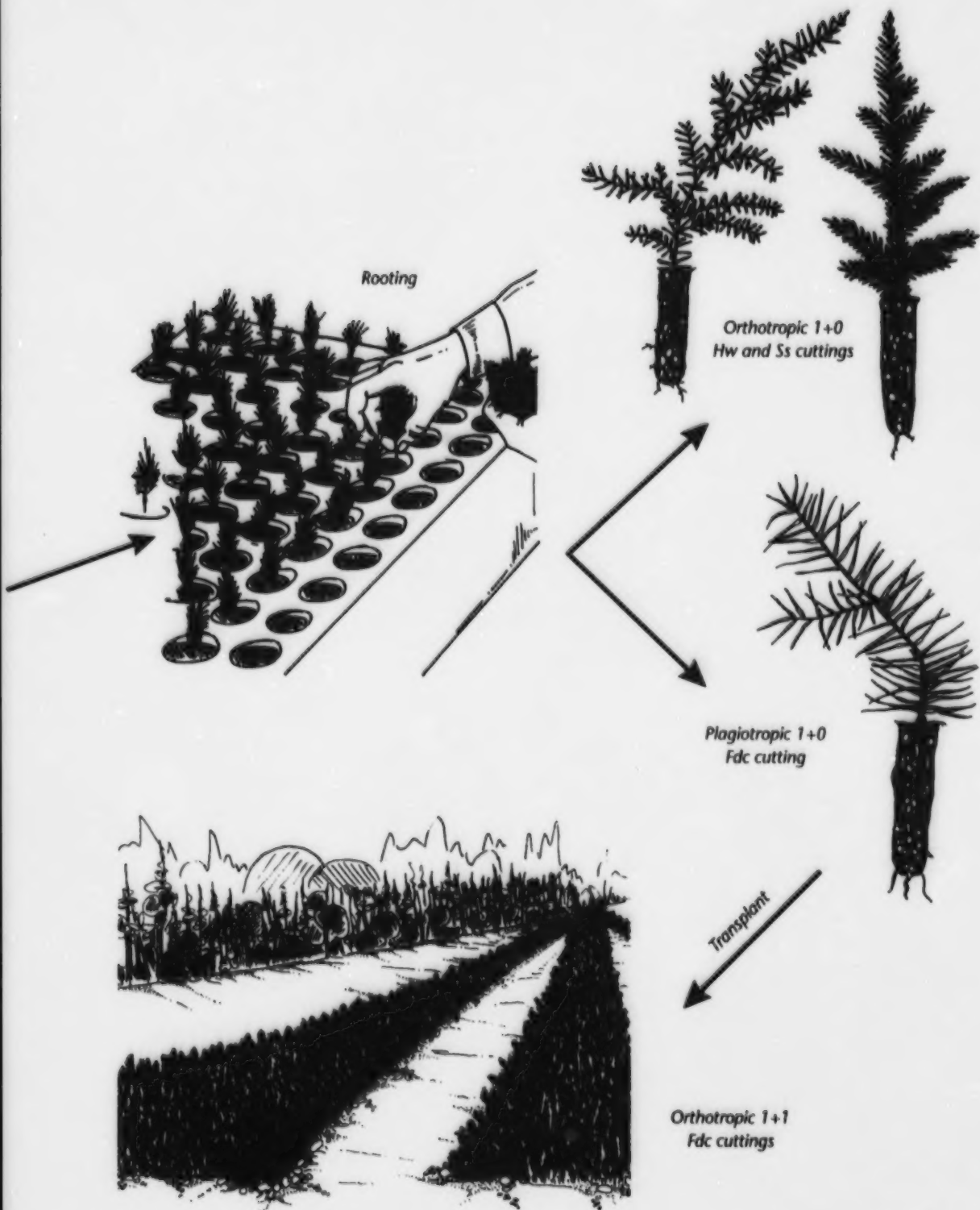


FIGURE 1 Overview of cultural procedures for production of juvenile rooted cuttings.



Seed source

- must meet Ministry standards for genetic diversity
-

Sowing stock plants

- January
 - single-sow
 - small-cavity containers
-

4.2 Seed Source

4.3 Sowing to Transplant

4.4 Transplant to Hardening-off

Transplanting stock plants

- May/June
 - 1-gallon pots
 - media:
 - peat moss with perlite and bark mulch
 - lime and micronutrients as desired
 - 3- to 4-month or 100-day formula slow-release fertilizer
 - top dress with grit or mulch
 - pinch leaders of Douglas-fir and Sitka spruce; do not pinch leaders of western hemlock
-

Cuttings from stock plants produced by these techniques are usually more plagiotropic; in 1+1 transplant production systems this is acceptable because the plant assumes orthotropic growth during its year in the nursery bed, but for 1+0 container crops these stock plant manipulation techniques are not very effective (an exception is yellow-cedar). Tissue culture techniques are promising but are not yet operational.

Neither hedging nor serial propagation is satisfactory for container cuttings of Douglas-fir or western hemlock, and they are only marginally satisfactory for Sitka spruce. Because propagation of families, not clones, is the objective, the problem of stock plant maturation can be avoided entirely by using annually produced stock plants from seed.

The 1-year-old seedling stock plants in this project supplied from 20 to 200 cuttings each, depending on the species and year.

This propagation project arose because of the availability of small lots of elite seed for reforestation. For Douglas-fir and western hemlock, these small seedlots consisted of full-sib families created through controlled pollination in seed or breeding orchards. In this project, the families were grown separately for trials or sometimes mixed together for pilot-scale commercial crops. The Sitka spruce seed used was from **open-pollinated families** developed in the Ministry's testing and selection program for weevil resistance. In the near future, however, a breeding program will be established that will provide full-sib seed (J. King, B.C. Ministry of Forests, pers. comm., 1999). All seed lots that are used to produce stock plants for cuttings destined for Crown land must satisfy Ministry standards for genetic diversity (Appendix 1).

The stratified seed was sown as early as possible in the sowing season, usually January, to ensure a transplantable seedling by spring. Seed was sown singly because of its high value, and was placed into a small-cavity Styroblock™; otherwise it was grown as a regular seedling crop. The objective at this stage was to produce an extractable plug as soon as possible.

4.4.1 Potting media The seedlings were transplanted into 1-gallon pots in May or June of the first year (some nurseries also experimented with various other containers; the Styroblock™ 1015 is the best of the alternatives).

Various potting media were used throughout the project, but no trials were done specifically on potting mix because most nurseries already had their own preferred recipe. The best mixes were fairly well-draining, allowing for a high number of wet-dry cycles during the growing season. Peat moss, perlite, and bark mulch in a ratio of about 3:1:1 works well, with specific ratio adjustments made to suit the nursery conditions and quality of ingredients. Dolomite lime and micronutrients were also incorporated.

Successful stock plant crops were grown both with and without slow-release fertilizer in the mix during this study. If no fertilizer was added to the mix, a higher concentration of liquid fertilizer was required during the growing season. When slow-release fertilizer was used in the potting mix, a 3- to 4-month formulation produced 18–24% more cuttings per stock plant than an 8- to 9-month formula, for all three species tested.

Top-dressing (mulching) the pots with a layer of bark mulch, grit, or sawdust was important, to keep the peat moss from drying out and to reduce moss, algae, liverwort, and weed growth.

Second pruning of stock plants

- Douglas-fir and Sitka spruce only; not western hemlock
- mid- to late July
- all lateral branch tips

4.4.2 Pruning and spacing Pruning the stock plants and spacing the pots is a technique that can be used to maximize the number of cuttings produced per stock plant. Alternatively, placing the pots closely together and not pruning produces tall stock plants and maximizes the number of cuttings produced per area of greenhouse space.

Various pruning regimes were tested. Both Douglas-fir and Sitka spruce produced most cuttings when pruned at the time of potting and again in mid- to late July. At potting, only the leader was pruned back. Just a small pinch was required, just enough to remove the apical meristem. At the second pruning in July, all lateral branch tips were pruned back in this manner. The pots were then spaced as far apart as possible. Pruning and spacing increased the number of cuttings per stock plant by 15–30% for Douglas-fir and Sitka spruce (Figure 2a).

An alternative method for Douglas-fir and Sitka spruce, especially when greenhouse space is a limiting factor and seed is relatively plentiful, is to *not* prune the plants and then to place the pots tightly together. This is the method used by Weyerhaeuser Company for their Douglas-fir stock plants (G.A. Ritchie, pers. comm.). In this way, vertical growth is encouraged, with many first-order branches and few if any second- or third-order branches. This results in a greater number of cuttings created per area of greenhouse than the pruning and spacing technique (Figure 2b).

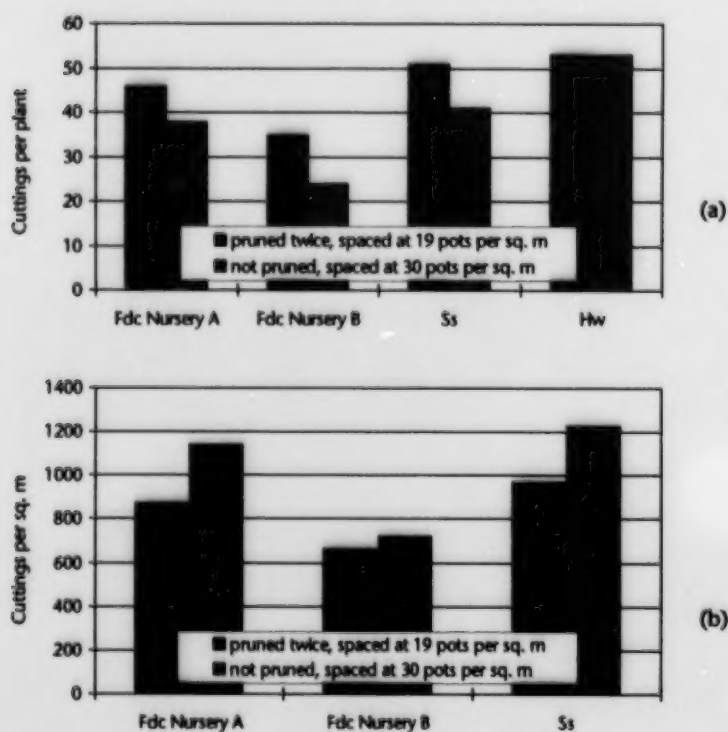


FIGURE 2 (a) Effect of pruning and spacing on the number of cuttings produced per stock plant. (b) Effect of pruning and spacing on the number of cuttings produced per square metre of greenhouse space.

Western hemlock stock plants when pruned produced the same number of or fewer branch tips than unpruned controls. This species has a different growth habit than Douglas-fir and Sitka spruce, and produces many branch tips on its own. For western hemlock only, pruning was tested with spacing (Figure 2a) and also independently of spacing. Pruning of western hemlock is not recommended. However, spacing was not tested independently of pruning and therefore a recommendation cannot be made regarding spacing of western hemlock stock plants.

For all three species, there was no difference in rootability between cuttings from pruned and unpruned stock plants.

Stock plant environment

- heat early and late in the season
 - photoperiod extension
 - keep covered
 - fertilize frequently
-

4.4.3 Environment Anecdotal evidence suggests that stock plants placed in a heated greenhouse for about 2 weeks after potting (usually the second half of June) produced far more cuttings than those that were immediately subjected to ambient temperatures. The effect of early establishment of these potted plants is apparently magnified throughout the growing season. During July and August the best environment was in a covered greenhouse with the sidewalls removed, with photoperiod extension lighting. Stock plants grown outside produced fewer cuttings, and those outside under shade even less. Sidewalls were put back on and the heat turned up in September, until dormancy induction treatments were begun. The timing of dormancy induction is discussed in Section 4.5.

The stock plants were irrigated thoroughly two to three times per week as required, and were fertilized at every irrigation with 150–200 ppm of nitrogen. Fertilization with only 75 ppm of nitrogen during the growing season resulted in chlorotic stock plants.

4.4.4 Specific cultural problems Nutritional deficiencies, particularly of iron and calcium, were common in Douglas-fir stock plants. Any tendencies for deficiency were magnified in these fast-growing seedlings. Calcium nitrate and chelated iron were included in each application of fertilizer to prevent deficiencies, and rates were adjusted as required. It was important to check foliar nutrient status during the growing season, because the health of the stock plant was an important factor in the rooting success of the cuttings.

Sitka spruce stock plants required more frequent irrigation than the other species. Accidental drought-induced budset in July or August occurred in at least some Sitka spruce plants at most nurseries and greatly reduced the number of cuttings produced.

For all species, soil leaching was sometimes required once during the growing season to remove excess salts. Insects, particularly aphids, were observed occasionally but were controlled when detected at an early stage. Mosses and liverworts were controlled by spraying with a saturated solution of potassium sulphate (Matthews 1994). Grey mould (*Botrytis*) did not occur if the plants were spaced well apart. For stock plants grown in closely spaced systems, drip irrigation rather than overhead irrigation can be used to reduce *Botrytis* infections (G.A. Ritchie, pers. comm.).

4.5 Dormancy Induction

Inducing stock plant dormancy

- late September
 - turn off lights; reduce heat and fertilizer
-

4.5.1 Timing and technique Stock plants should be partially lignified before cuttings can be successfully harvested. Thus dormancy was initiated in the fall to prepare the plants for winter cuttings. The timing of dormancy induction had a significant effect on the quality and quantity of cuttings produced.

The second half of September was the best time to start shutting down the stock plants of all species. When dormancy was induced at this time, the plants reached the proper stage of semi-lignification before activity ceased. Those shut down earlier became too woody, while those pushed later into the season remained too succulent. That is, no matter what time the plants were shut down, they reached a point after a few weeks where no further development occurred, and the state of lignification that they had attained then remained fairly constant throughout the winter. The best cuttings were those that were semi-lignified and without large buds. The appropriate degree of lignification is best described as when the stem is whitish; a green stem was too succulent and a brown stem was too lignified. Moisture content was found not to be a reliable indicator of the proper stage of lignification in this study.

Shutting the stock plants down in late September also optimized the number of quality cuttings produced. Initiating dormancy in August resulted in significantly fewer cuttings, while an October or November shut-down resulted in more cuttings but a significantly lower rooting percentage. This may be due to the physical characteristics of succulent cuttings, and/or a lack of sufficient chilling.

A Douglas-fir stock plant as it appeared just prior to dormancy induction is shown in Figure 3. With the shorter natural daylength in September, simply returning to natural daylength initiated dormancy. The heat was reduced gradually, taking care to avoid frost damage, and the liquid fertilizer was reduced to a finisher regime alternating with water. The stock plants were maintained this way until the cuttings were harvested, sometime from December through March.



FIGURE 3 Eight-month-old Douglas-fir stock plant.

4.5.2 Foliar tissue nutrient levels at harvesting The optimal concentrations of foliar nutrients at harvesting are unknown.

Nitrogen In one trial, Sitka spruce rooted equally well with foliar N concentrations of 1.2–2.3%, and western hemlock rooted equally well with foliar N concentrations of 1.1–1.8%. Douglas-fir was found to be more sensitive to changes in N level, with 1.7–2.0% at harvesting probably the most optimal.

Iron and Manganese Low foliar Fe (i.e., below 60 ppm) reduced rooting in Douglas-fir and Sitka spruce. High Mn levels in Sitka spruce were correlated with plagiotropic growth at two nurseries, but no such relationship was found for Douglas-fir.

4.6 Serial Propagation and 2-year-old Stock Plants of Sitka Spruce

Serial propagation and hedging of Sitka spruce were explored because of an especially limited seed supply. Also, these technologies are used for Sitka spruce in the U.K.

In this project, cuttings serially propagated from 1-year-old containerized cuttings were plagiotropic when grown as 1+0 container stock. Sitka spruce cuttings in the U.K. are grown as 1+1 transplants and given rigorous undercutting and wrenching treatments, so the cuttings are able to overcome their plagiotropism before lifting. However, in British Columbia, where Sitka spruce stock is entirely containerized, serial propagation is not recommended. There is also evidence in the U.K. that second- and third-cycle serially propagated cuttings may not be growing as well in the field as first-cycle cuttings (Mason and Sharpe 1992).

Although not the most common procedure, hedging is done with Sitka spruce at some private nurseries in the U.K., in order to reduce costs. Sitka spruce stock plants are kept in pots in the greenhouse and hedged for up to 6 years in these nurseries. Rooting percentage declines with increasing height and age of hedges, with 6 or 7 years being the maximum age (Morgan and Mason 1993).

In this project, some Sitka spruce stock plants were hedged at age 1 year and kept in pots in a greenhouse until they were 2 years old. Cuttings from these 2-year-old stock plants rooted significantly less than those from 1-year-old stock plants of the same families. The cuttings from the older stock plants were also significantly more plagiotropic and had a higher incidence of multiple leaders. However, the results may have been confounded by different physiological stages of the two stock plant crops when the cuttings were taken. Further nursery and field studies are in progress. When more information becomes available, the Ministry of Forests will make a policy decision regarding the use of this material.

5 ROOTED CUTTING PRODUCTION

5.1 Rationale

-
- Requirements of a
plantable rooted cutting*
- meet size specifications
at lifting
 - cohesive plugs
 - physiologically ready for
lifting at the appropriate
time
 - orthotropic
-

Successful cutting programs with Douglas-fir and Sitka spruce in other parts of the world use a bareroot-transplant production system. In British Columbia, however, the preference at the present time is for container stock.

Rooted cuttings in British Columbia are grown to the same specifications that apply to seedlings of the same species and container size. They will also likely have to be orthotropic in form and have a dominant leader, although Weyerhaeuser Company has found that mild plagiotropism and multiple leaders on Douglas-fir bareroot rooted cuttings are undetectable in the field after 2–3 years (G.A. Ritchie, pers. comm.). Most western hemlock and Sitka spruce seedlings in British Columbia are grown as a 1+0 spring plant, which means that stock is lifted in late fall and cold-stored for planting the following spring. Hence the emphasis in this study was on the production of 1+0 spring plant rooted cuttings. Sitka spruce cuttings were also produced as 1+0 fall plant.

Because Douglas-fir cuttings required transplanting to achieve orthotrophy, they did not fit easily into a 1+0 cycle. Container (plug-to-plug) transplants were grown both as 1+0 and 2+0 crops with mixed success.

5.2 Taking Cuttings

Type of cuttings

- tips only, not basal stem or branch section
- avoid the terminal
- cuttings from the lower third of the plant may root best
- uniform size approximately 6 cm

5.2.1 Time of year Little change occurred in stock plant lignification from December through February, and rooting percentages of cuttings did not change during this period, so the choice of timing for taking the cuttings could be based on other logistical considerations. However, this also meant that if the cuttings were too succulent or too woody there was no recourse at this point. Cuttings that were too succulent were difficult to insert into the media, so the process was both slower and more expensive, and there was more frequent damage to the cutting.

Cuttings may be stored after severance from the stock plants (see Section 5.2.5), so the date of taking the cuttings does not necessarily have to be the same as the date for setting them (discussed in Section 5.3.1).

5.2.2 Harvesting technique Two harvesting techniques were used. In one method, the stock plant was cut off at the base and cuttings were taken by laying the branches on a board and slicing through the stems with a utility knife (Figure 4). This method is described in Russell and Ferguson (1990). The other method is to leave the stock plant intact and harvest branch tips with secateurs or scissors, as described in Tousignant et al. (1996). The length of the cuttings can be measured against a mark on the worker's finger. This method is just as fast and allows the stock plants to be kept for another use if desired.



FIGURE 4 Taking cuttings from harvested Sitka spruce stock plants.

5.2.3 Length of cutting Cuttings of a uniform length (i.e., within 2 cm of each other) were more efficient to handle during setting, and produced a more uniform final crop. To get the maximum number of cuttings from the stock plants, a size range of about 4–6 cm was established, because there were often many short branches approximately 4 cm in length. If cutting material was plentiful, a slightly larger size range such as 6–8 cm could be used. There were no consistent or significant differences in rootability between cuttings of 4 cm and 8 cm in length.

5.2.4 Position on stock plant The performance of tip (end of branch) versus basal cuttings was observed for all species, and it was determined that only tip cuttings should be used for a 1+0 container product. Basal branch cuttings rooted well, but resulted in plants with stem deformities or multiple tops.

The propagation systems that use basal branch cuttings for these species, including those of Douglas-fir in the U.S. and of Sitka spruce in the U.K., produce 1+1 transplants. In these systems, the plants are able to produce a dominant leader through proper cultivation in the nursery bed in their second year.

Terminal leader cuttings of Douglas-fir and Sitka spruce often produced plants with multiple leaders, because the terminal bud did not flush.

One experiment was done to track the performance of Douglas-fir cuttings from the upper, middle, and lower thirds of the stock plant, and from first- and second-order branches. It was found that cuttings from the lower third of the Douglas-fir stock plants rooted at twice the percentage as those from the upper third. Those from the middle third of the crown were in between. This result may have been caused by shading of the lower branches, by differential degrees of bud dormancy, or possibly by maturation effects, even though the plants were less than 1 year old. There was no consistent difference in rooting or subsequent growth between cuttings from first- and second-order branches. The cuttings from all positions were equally plagiotropic.

5.2.5 Storage of cuttings Storage of cutting material may be useful for logistical reasons in the nursery. Sitka spruce cuttings in this project rooted at least as well after 2 weeks of cold (2°C) storage as they did when set immediately. The stored cuttings were re-cut when they were set, by removing a few millimetres of the stem to expose fresh tissue. However, re-cutting was later found to be unnecessary for stored western hemlock and is probably not necessary for Sitka spruce either.

With Douglas-fir cuttings, cold storage for 24 hours reduced rootability. However, these cuttings were not adequately lignified. Weyerhaeuser routinely freezer-stores (-1°C) Douglas-fir cuttings for up to 4 months prior to setting (Ritchie 1993).

5.3 Setting Cuttings

When to set cuttings

- For 1+0 spring plant:
 - western hemlock: January
 - Sitka spruce: late January or February
- For transplant stock:
 - Douglas-fir: from November on

5.3.1 Time of year Western hemlock cuttings set in January produced the best 1+0 spring plant crops, while Sitka spruce cuttings set in late January and February were best. If Sitka spruce was set earlier it made good summer or fall plant stock, but often presented height control problems for spring plant.

Douglas-fir was altogether different because it rooted more slowly, and because it did not lend itself to 1+0 production. To co-ordinate with other species in a greenhouse, Douglas-fir was set the earliest, any time from November to January. If set in November or December in a small-cavity Styroblock™, Douglas-fir cuttings were ready for transplanting in the spring.

5.3.2 Container Containers used for experimental work were Styroblocks™ of various sizes, because these are the industry standard in British Columbia. Under ideal conditions most cavity sizes were equally as good for rooting; however, deeper cavities such as the PSB415B required more heat input than the shorter PSB410.

5.3.3 Rooting media Most experiments conducted at the Cowichan Lake Research Station and the Nursery Extension Services used a 3:2 ratio of peat:perlite as a rooting medium. No specific media trials were done because most nurseries had already developed their own preferred rooting mix. Holes were pre-dibbled in the cavities using a nail template, first described in Russell and Ferguson (1990).

Forest seedling nurseries in British Columbia top-dress all container seedlings with coarse forestry sand or "grit," to inhibit moss and liverwort growth, to prevent the surface from drying out, and to hold the seed in place. The grit layer is normally applied immediately after seeding. This grit layer was also beneficial for cuttings, but was more difficult to apply. With some species the grit can be sprinkled on after setting the cuttings, but with Sitka spruce, because of its three-dimensional shape and stiff needles, applying the grit afterwards resulted in most of the grit getting stuck in the needles and very little landing on the peat moss. With Sitka spruce it was better to apply the grit to the blocks *before* setting the cuttings. Then, as long as the grit was kept moist, the holes could be dibbled without the grit falling into them and the cuttings could be set through the grit layer (Figure 5). This also allowed the blocks to be machine-gritted when they were filled, which saved time.

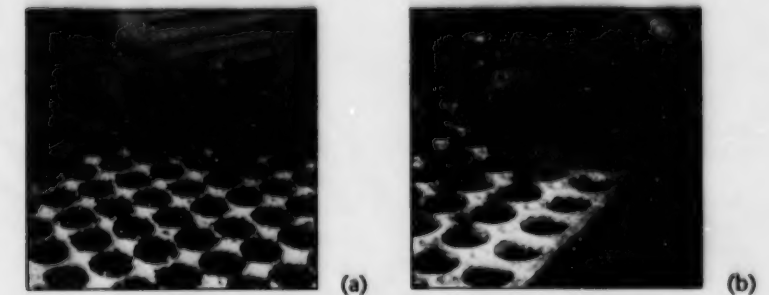


FIGURE 5 Setting cuttings: (a) Douglas-fir with liquid rooting hormone, (b) Sitka spruce with no rooting hormone.

5.3.4 Plucking of lower needles Removing the lower needles did not improve the rooting of any of the three species. In some cases it made handling easier; in others it did not. It was thus a matter of personal preference. The exception was when using a powdered rooting hormone (which is not recommended); it was better to remove needles to prevent clumping of the hormone.

5.3.5 Rooting hormones Rooting of western hemlock and Douglas-fir cuttings was improved in both by a quick (1–2 second) dip in liquid rooting hormone. Liquid hormone solutions always performed better than powders. Western hemlock rooted optimally with a solution of indole-butyric-acid (IBA) at 10 000 ppm (the product used was liquid Stim-Root®). Douglas-fir rooted best with a combination of IBA and naphthalene-acetic-acid (NAA) such as that found in Dip'N Grow®, but, because this product is not registered or available in Canada, liquid IBA is recommended. The optimal concentrations of IBA for Douglas-fir were from 5000 to 10 000 ppm, with the lower amount best for semi-lignified cuttings and the upper amount best for fully lignified cuttings.

Sitka spruce cuttings from 1-year-old stock plants did not benefit from application of any rooting hormone tried. Rooting hormones are not used with Sitka spruce cuttings in the U.K. (Morgan and Mason 1993). Use of a rooting hormone with this stocktype is not recommended.

Cutting preparation

Rooting hormone:

- Sitka spruce (1-year-old): no rooting hormone
- western hemlock: quick dip in liquid 10 000 ppm IBA
- Douglas-fir: quick dip in IBA/NAA combination if available or else in 5000–10 000 ppm IBA
- older Sitka spruce may benefit from rooting hormone

Needle removal:

- not necessary unless using powdered rooting hormone

Rooting of Sitka spruce from 2-year-old stock plants, unlike the 1-year-old material, was improved slightly with rooting hormone, using 5000–10 000 ppm IBA depending on the extent of lignification.

5.4 Rooting Cuttings

Rooting cuttings

- soil temperature 16–18°C (Sitka spruce best at 16°C)
- high humidity but not soggy
- benefits of fungicide on rooting not proven
- fertilize after most cuttings have started to root

5.4.1 Environment Cuttings were rooted in an environment of high humidity and warm soil. Western hemlock rooted equally well at soil temperatures of either 16 or 18°C. Sitka spruce rooted better at 16 than at 20°C. The optimum soil temperature for Douglas-fir was not tested, but Ross (1975) reported good results at 20°C.

Achieving optimum humidity is always a difficult balance between reducing transpirational stress on the cuttings and not allowing the soil to become waterlogged. The actual misting regimes used were highly specific to each facility.

5.4.2 Fungicide Application of fungicide (either as a drench or as a dip) to improve rooting has often been recommended in the literature. In this project, however, fungicides were not shown conclusively to enhance rooting for any species. In one early study with Sitka spruce, a benomyl drench improved the speed of rooting and the rooting percentage of the cuttings, but the results were not repeatable.

5.4.3 Fertilizer Fertilizing early in the rooting stage (foliar feeding) did not improve the rooting or growth of Douglas-fir or Sitka spruce cuttings. It was not tested on western hemlock. Regular fertilizing was begun when the majority of cuttings had some roots and/or when cuttings began to flush.

5.4.4 Weaning to a seedling regime Roots first appeared on western hemlock and Sitka spruce cuttings after about 5–6 weeks in the rooting environment. Douglas-fir was slower, with the first roots appearing at about 7–8 weeks.

By 10–12 weeks after setting (12–15 for Douglas-fir), the cuttings had developed enough roots to be weaned off the misting regime and transferred to a normal seedling growing regime (Figure 6). The misting was gradually reduced over a period of a few days.

From rooting regime to growing regime

- western hemlock and Sitka spruce:
 - first roots appear at 5–6 weeks
 - can be weaned to a growing regime at 10–12 weeks
- Douglas-fir:
 - first roots appear at 7–8 weeks
 - can be weaned to a growing regime at 12–15 weeks

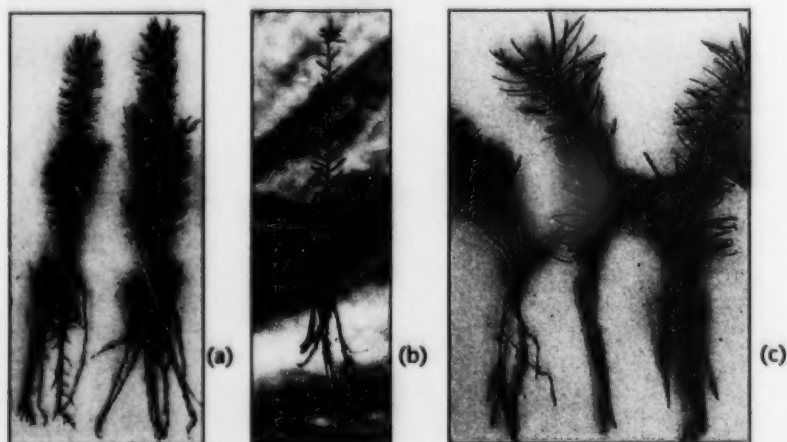


FIGURE 6 Rooted cuttings: (a) Sitka spruce at 12 weeks, (b) western hemlock at 13 weeks, (c) Douglas-fir at 16 weeks.

The rooting percentages obtained during this project were:

- Douglas-fir: from 39 to 73% for different years and facilities.
- western hemlock: about 90% in most years and facilities.
- Sitka spruce: about 80% in most years and facilities, but up to 99% in some trials.

5.5 Growing the Rooted Cuttings

After being weaned off the misting regime, western hemlock and Sitka spruce were grown as 1+0 spring plant container crops. Growing rooted cuttings of these species was no different than growing seedlings, and therefore will not be discussed, except for techniques to minimize plagiotropism and multiple tops.

All attempts to produce 1+0 spring plant container crops of Douglas-fir resulted in plagiotropic trees. Plug-to-plug transplanting was occasionally successful in producing orthotropism, but results were not consistent from year to year or for all families (Figure 7). Bareroot transplanting was the only reliable method of producing an acceptable Douglas-fir rooted cutting. Production of a transplantable plug for Douglas-fir required a minimum of 5 months from setting (Figure 8). Growing bareroot transplants of Douglas-fir cuttings was not the objective of this project, however, as Weyerhaeuser has already developed a proven technique (Ritchie 1993).

Reducing plagiotropism

- avoid drought or heat stress
- avoid over-watering
- avoid excess nitrogen
- outdoors in full light
- Douglas-fir is best as a 1+1 transplant



FIGURE 7 1+0 Douglas-fir cuttings grown as plug-plug transplants into a PSB615.



FIGURE 8 Douglas-fir cutting at 5 months, just ready for transplanting.

Juvenile Sitka spruce cuttings were the least likely of the three species to exhibit plagiotropism; for this species it often occurred only around the edges of the crop (Figure 9). What causes plagiotropism is not completely understood, but any type of stress can increase its likelihood. Minimizing drought and heat stress, growing the cuttings outdoors in full light, avoiding over-watering, and avoiding excessive nitrogen levels helped to improve growth habit. Sitka spruce cuttings also had a more frequent occurrence of forking and multiple leaders than seedlings did. One small experiment suggested that pruning of competing leaders could produce a cutting with good form if it was done early in the growing season (T. Hale, Cairnpark Nursery, pers. comm., 1999).

Western hemlock cuttings tended to form a matted canopy (Figure 10), even more so than seedlings. Gently untangling, or combing, the western hemlock cuttings helped them grow upright. With small crops this was done by hand.



FIGURE 9 *Sitka spruce cuttings, showing slight plagiotropism at the edge of the block.*



FIGURE 10 *Western hemlock cuttings and seedlings, showing the more matted growth of cuttings.*

6.1 Problem Definition

Plagiotropism is a non-vertical growth pattern. It is the normal state of branches on intact plants, and is presumably mediated through apical control. Cuttings severed from the stock plant, although released from apical control, frequently continue to grow plagiotropically. Rooted cuttings that are plagiotropic often have a needle arrangement that is bilateral rather than radial, and a planar rather than radial branch pattern, in addition to the oblique stem angle.

Under less-than-ideal growing conditions, it may take several years for rooted cuttings to resume orthotrophy. In one study, 1+0 containerized Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) cuttings were planted at two sites depending on their vigour. The most vigorous were planted at a field site, while the remainder were transplanted into a nursery bed for another year. Virtually all of the cuttings were initially plagiotropic at both sites. The cuttings in the nursery bed were irrigated, fertilized, and weeded over the next year. After 1 year, nearly all of the cuttings in the nursery bed were orthotropic, while those in the field were still plagiotropic (Myers and Howe 1990).

Persistence of plagiotropic growth in the field will counteract genetic gain. Furthermore, plants that have resumed orthotropic growth may have basal crooks or other stem defects. Plagiotropism occurred to some degree in all three species during this project, but with containerized Douglas-fir cuttings it was considered severe enough to prevent their operational use.

6.2 Contributing Factors

An understanding of the basis for plagiotropic growth has remained elusive. It appears to involve a complex interaction of physiological, environmental, and genetic factors.

Maturation Cuttings from juvenile (as compared to mature) plant tissue are more likely to grow orthotropically. Also, first-order branch cuttings are often more upright than higher-order branch cuttings (Power et al. 1988). However, Ritchie and Long (1986) showed that micro-propagated Douglas-fir plantlets from cotyledonary tissue were plagiotropic. This does not support the idea that plagiotropism is a function of maturation since cotyledonary material is presumably very juvenile (G.A. Ritchie, pers. comm.).

Branch-angle "memory" Some suggest that plagiotropism in cuttings is a branch-angle "memory." Starbuck et al. (1983) showed that recently excised Douglas-fir cuttings placed horizontally or vertically would bend so as to restore their original orientation. However, micro-propagated plantlets from cotyledonary tissue are also plagiotropic (Ritchie and Long 1986). The phenomenon of branch-angle "memory" does not explain this response. Also puzzling is that Norway spruce (*Picea abies*) stock plants whose branches were forced to grow vertically in the season prior to taking cuttings, produced cuttings that were *more plagiotropic* than non-manipulated donors, even when the terminal leader had been removed (Bentzer 1988). Nevertheless, the branch-tip cutting is clearly able to detect and respond to gravity. Worrall (1984), and Worrall and Little (1986), showed that branch-tip meristems of *Abies* spp. were not radially symmetrical, and that this plagiotropy was gradually imposed on them during the season prior to their growth. They found that buds were more vigorous when maintained in the same orientation to gravity in which they were formed, and that the buds themselves were the site of gravity perception.

Compression wood Normal branch angle is maintained in intact plants through the formation of compression wood, regulated partly by auxins synthesized in the terminal bud of the leader. How this branch angle may be maintained in cuttings in the absence of a dominant apical bud has not been explained. Compression wood was found on the adaxial stem surface of plagiotropic Douglas-fir cuttings (Starbuck and Roberts 1983). However, Edson et al. (1996) did not find compression wood formation in plagiotropic western larch cuttings. Nor did Wise et al. (1986) find compression wood in succulent plagiotropic Fraser fir (*Abies fraseri*) cuttings, although they did find that compression wood formed during the second growing season maintained the existing curvature of the stem.

Phytohormones There is inconclusive evidence that auxins accumulate differentially on the adaxial side of Douglas-fir cuttings (Starbuck and Roberts 1982). An asymmetric distribution of auxin across the stem, stimulating the formation of compression wood, may contribute to plagiotropism in woody Douglas-fir cuttings (Starbuck and Phelps 1986).

Cytokinins, which are synthesized in roots, have also been implicated as a contributing factor to plagiotropic growth. Tissue-cultured shoot explants of Douglas-fir displayed characteristics of mature cuttings, including plagiotropism, when the culture medium was impoverished in cytokinin (Matschke and Weiser 1988). Also, plagiotropic blue spruce (*Picea pungens* ssp. *glauca*) cuttings had a reduced ratio of cytokinins to auxins compared to orthotropic cuttings (Matschke 1993).

Ethylene may be involved in mediating the effects of gravity change in disoriented branch tips (Worrall and Little 1986). Application of ethylene caused branches of *Cupressus* to turn upwards, while branches of plants grown in an atmosphere devoid of ethylene grew downwards (Blake et al. 1980). Ethylene was also the only one of several growth regulators that counteracted the curvature of succulent Douglas-fir cuttings in a laboratory experiment, although the authors say that the effect was not statistically significant (Starbuck et al. 1983).

Root asymmetry Timmis et al. (1992) proposed that plagiotropism in micro-propagated Douglas-fir plantlets was caused by an asymmetrical root system. As mentioned earlier, these plantlets were propagated from cotyledonary tissue and therefore were unlikely to have acquired a branch-angle memory. Furthermore, they found that plagiotropic plantlet tops, when grafted onto seedling root systems, grew nearly orthotropically; and conversely, that seedling tops grafted to plagiotropic plantlet rootstock became plagiotropic. Thus they hypothesized that an incomplete vascular connection between root and shoot was a cause of plagiotropism. This theory was later disproved, and there is no satisfactory theory yet to explain the results of the reciprocal grafting experiment (G.A. Ritchie, pers. comm.).

Root confinement Containerized Douglas-fir cuttings in a greenhouse maintained plagiotropic growth indefinitely, but once transplanted into a nursery bed they rapidly became orthotropic (Ritchie et al. 1997). Thus it was speculated that root confinement prevented the transition to orthotropic growth. Ritchie et al. (1997) found, however, that rooted cuttings transplanted into a nursery bed within the confines of a hard plastic container

also assumed orthotropic growth. They concluded that some characteristic of the greenhouse environment, other than root confinement, was responsible for the persistence of plagiotropism.

Light Plagiotropism is apparently accentuated under greenhouse conditions compared to the outdoors (e.g., Skrøppa and Dietrichson 1986; Ritchie et al. 1997). One reason could be the difference in light levels. In loblolly pine cuttings grown at different light levels, plagiotropism increased as light intensity decreased (Wise and Caldwell 1994). However, the evidence for the effect of shading on plagiotropism of Douglas-fir cuttings is conflicting (Ritchie et al. 1997).

Genetics Several studies have reported significant clonal variation in plagiotropism, although usually as an aside to the main focus of the study. Johnsen and Skrøppa (1992) thus undertook a large study of the variation in plagiotropism of Norway spruce cuttings at the provenance, family, and clonal levels. They found that the provenance effect was highly significant, the family effects were significant in one provenance but not the other, and the clonal variance components were as large as, or larger than, the family components. They note that some clones were heterogeneous for plagiotropism, others were homogeneous for plagiotropism, and some were orthotropic.

6.3 Observations from this Project

One experiment looked at branch-tip cuttings from different crown positions on Douglas-fir stock plants, and from first-order and second-order branches. Cuttings from the upper, middle, and lower thirds of the crown, and from all branch orders, were equally plagiotropic. It was concluded that with such young plants (less than 1 year old) there was not enough difference in maturation of tissues. Terminal leader cuttings were also plagiotropic in this study, although in a different way than branch-tip cuttings: plagiotropism in terminal cuttings was characterized by the flushing of a sub-terminal bud, which then grew at an oblique angle (Figure 11).



FIGURE 11 Diagram of two types of plagiotropism found in Douglas-fir cuttings: (a) cutting with bent stem, and (b) cutting with unflushed terminal bud and plagiotropic sub-terminal branch.

Orthotropic growth in Fraser fir cuttings may be related to a large root:shoot ratio (Wise et al. 1986). Plagiotropism was significantly positively correlated with a low root:shoot ratio in Douglas-fir in one experiment during this project. No other growth factors were related to plagiotropism, including height, root-collar diameter, or number of roots. However, subsequent studies that focused on cultural techniques to manipulate root:shoot ratio were inconclusive. In fact, in one study plagiotropism was correlated with a *high* root:shoot ratio.

Short-day treatments that significantly affected the root:shoot ratio did not affect the stem angle. Removing competing leaders early in the growing season also increased the root:shoot ratio but did not affect stem angle. Douglas-fir cuttings were also rooted in CopperBlock™ containers to effect a different root architecture. The cuttings in these copper-coated Styroblocks™ rooted as well as those in the regular Styroblocks™ and showed no difference in degree of plagiotropism despite having a more branched root system.

Transplanting from small containers into larger ones was a promising approach. In the first trial, approximately 65% of Douglas-fir cuttings transplanted from PSB310 (54 ml) rooting containers into PSB615 (345 ml) containers achieved orthotropic growth. However, in two subsequent trials, virtually all of the cuttings remained plagiotropic. The relative success of the first trial is attributed to a fortunate combination of timing, climate, fertilizer, and light levels that has not been achieved since. Further work could perhaps explain more precisely the conditions required. Currently, however, this method is expensive and unreliable. What has been gathered from this work in terms of culture of Douglas-fir cuttings in containers is that 1) as much natural light as possible is beneficial, and 2) heat stress, drought stress, and over-watering all increase plagiotropic behaviour.

Observations of Douglas-fir cuttings in different nurseries suggested that the level of nitrogen fertilization had an effect on growth habit. In a hydroponic trial, however, while there was a trend of increasing plagiotropism with an increasing N level, it was only weakly significant ($p=0.10$).

Root confinement was also related to plagiotropism. In a trial similar to that in Ritchie et al. (1997), Douglas-fir cuttings were transplanted to a nursery bed within the confines of a hard plastic tube-like container, or as normal bareroot transplants. Many of the cuttings' root systems expanded out of the drainage holes of the containers and these cuttings were all orthotropic, as were the bareroot transplants, but those with root systems that remained confined had plagiotropic shoots. It is not clear if root confinement influenced plagiotropism, or if a general lack of vigour contributed to both the reduced root growth and the plagiotropic shoots.

There was a great deal of variability in plagiotropism within full-sib families. This made it difficult to discern families, although occasionally one family appeared that was visibly better or worse than the others. Most genetic variation in plagiotropism was at the clonal level. Selection of clones for Douglas-fir is not currently an option, but with the development of tissue culture techniques, this may be an option for the future.

6.4 Summary of Nursery Techniques to Reduce Plagiotropism in Douglas-fir Cuttings

In containers, plagiotropism can be reduced but not eliminated through exposure to natural light, avoidance of stress, encouraging vigorous root systems, and transplanting into larger-cavity containers after rooting. There is a strong clonal effect on plagiotropism. Growing as a 1+1 stocktype is still the only reliable method for producing orthotropic Douglas-fir cuttings.

The B.C. Ministry of Forests has technical standards for the genetic diversity, registration, and transferability of vegetatively propagated material planted on Crown land. Standards for genetic diversity include the effective population size (N_e), the minimum number of genotypes, and deployment. (See Appendix 1 for a description of the Ministry guidelines.)

These genetic standards theoretically refer to the material leaving the nursery. However, it is far easier to apply the standards at the seed stage. Tracking family identity throughout the nursery process to ensure equal representation, then mixing them together for lifting, is quite onerous compared to mixing seed of several families together. Thus in practice the genetic standards are applied at the beginning, to the seedlot that will be used to grow the stock plants, and it is assumed that the effective population size and minimum number of genotypes will not be altered significantly by the nursery process.

The steps in the nursery process that could potentially affect the genetic make-up of the vegetative lot include seed germination, the number of cuttings produced per stock plant, the rooting percent of the cuttings, and the number of trees culled at lifting. Throughout this project, family information was collected from many of the experiments. While there was little variation among the open-pollinated Sitka spruce, some significant differences were found among the full-sib families of Douglas-fir and western hemlock.

Table 1 shows the effects of each nursery procedure on the genetic make-up of one crop of western hemlock cuttings. There were differences among families at each nursery stage, except for lifting. Similar results were obtained for other western hemlock crops during the project.

During this project, there was evidence that the genetic make-up of the rooted cutting crop differed from that of the original seed lot, when full-sib

TABLE 1 *The proportion of each family within a western hemlock vegetative lot, before and after bulking-up in the nursery*

Family	Initial proportion of veg. lot (as seed)	Germination %	Cuttings per stock plant	Rooting %	Proportion of crop before lift	Liftable %	Final proportion of crop
41 × 31	.11	94	59	91	.17	95	.17
441 × 687	.11	64	39	87	.07	96	.07
1004 × 459	.11	0	-	-	.00	-	.00
2020 × 2166	.11	74	66	92	.15	94	.15
2156 × 2157	.11	14	25	98	.01	94	.01
2360 × 2232	.11	80	49	94	.12	91	.12
1161 × 1191	.11	86	63	87	.15	90	.15
1230 × 1296	.11	96	58	95	.17	95	.17
5030 × 1161	.11	66	71	90	.14	95	.14
$*N_e = 16.5$							$N_e = 12.3$

* N_e is defined in Appendix 1.

families were used. In order to ensure sufficient diversity of the rooted cutting crops, without having to grow them by family, it may be beneficial to include, in the original seed lot, more than the minimum number of parents and genotypes required to meet Ministry of Forests technical standards.

8 FIELD TRIALS

Comparing the field performance of rooted cuttings with that of seedlings is important. While rooted cuttings from juvenile stock plants are sometimes indistinguishable from seedlings in the field, some cuttings have shown different growth patterns that may affect their value as forest trees. Diameter growth is sometimes less in cuttings than seedlings, but, on the other hand, cuttings may have fewer and smaller branches, resulting in higher-quality wood (Frampton and Foster 1993; Ritchie 1994).

During this project, an existing Douglas-fir field trial was assessed and tests for western hemlock and Sitka spruce were established. In all of these trials, the approach was to compare same-aged cuttings and seedlings from the same families.

The Douglas-fir test was established at one high-quality site near Campbell River, B.C., in 1991, with 280 trees from six full-sib families. Cuttings and seedlings were orthotropic 1+1 plants of approximately equal size at planting. During the project reported here, this test was assessed at ages 7 and 10 years. There were no differences between cuttings and seedlings, in either height or dbh (diameter at breast height), at either measurement date.

There were no existing seedling-cutting comparisons for western hemlock prior to this project, although there is one existing genetic study of cuttings (Paul et al. 1993). A trial was thus established in spring 1998 using 1+0 seedlings and cuttings from seven full-sib elite families with non-related parents. The trial was established on five sites in the low-elevation wet maritime with a total of 2800 trees. The height and root collar diameter of each tree were measured at planting and again after 1 year in the field. At age 2 years, the stocktypes were visually indistinguishable and there was no difference in survival. However, the seedlings were taller and had greater diameters than the cuttings on all sites despite being of equal size at planting.

Different propagule types may have different growth patterns over time, so early measurements may not be indicative of later results (Frampton and Foster 1993). Those authors recommend early and frequent measuring of seedling-cutting field comparisons, in order to document the temporal differences in growth patterns. This trial will be reassessed at ages 3 and 5 years.

In the U.K. and elsewhere, field results with juvenile Sitka spruce cuttings have been consistently good (see Section 2.2); however, these were generally established with 1+1 transplant stocktypes. In one early study in British Columbia, Sitka spruce cuttings had poorer survival and growth than seedlings, but these were cuttings from mature (17- and 19-year-old) trees (van den Driessche 1997).

A new field trial was established as part of this study in spring 1999, using 1+0 cuttings and seedlings from seven open-pollinated families from the Big Qualicum provenance with high rankings for weevil resistance. This trial was established on three sites. After one growing season, there were no differences between the cuttings and the seedlings in either height growth, diameter growth, or survival.

The B.C. Ministry of Forests has technical standards for the use of vegetatively propagated material on Crown land. Refer to the *Forest Practices Code of British Columbia Seed and Vegetative Material Guidebook* and its updates, and the *Technical Standards for the Registration of Seed and Vegetative Material Derived from Seed Orchards and Production Facilities*, available from the Ministry of Forests, for complete information.

Genetic diversity Guidelines have been established by the Ministry of Forests to ensure that there is sufficient genetic diversity in vegetatively propagated crops to keep the risk of plantation failure from unknown causes at levels similar to those of natural stands. These guidelines apply to all material planted on Crown land in British Columbia. The diversity guidelines include effective population size (N_e), minimum number of genotypes, and deployment.

Effective population size The effective population size N_e is a measure of the genetic diversity of a vegetative lot, based on the proportional gamete contribution of each unrelated parent to the lot.

$$N_e = 1/\sum(P_i^2)$$

where P_i is the proportional gamete contribution of the i th parent.

All vegetative lots must have originated from sufficient parents to have an N_e greater than or equal to 10, for unconditional registration.

Minimum number of genotypes In addition to the requirements for parental N_e , each vegetative lot must have the following minimum number of genotypes (each cutting stock plant grown from a seed is a genotype): 20 for lots from tested clones; 30 for lots derived from tested full-sib, open-pollinated, or poly-mix families; and 200 for lots derived from untested material.

Deployment Planting of clonal or family blocks is not acceptable under the technical standards. The families within each vegetative lot must be mixed together for deployment.

Registration Registration may be unconditional, which allows unlimited use of the material within the constraints of transfer guidelines and silviculture prescriptions, or conditional, which allows for some limited and controlled use.

Lots produced by a licensed facility that meet the required standards for genetic diversity, genetic worth, and field testing may be given an unconditional registration. A separate registration is required for each genetically unique lot.

If one or more of the technical standards are not met, a lot may be given conditional registration if it is seen to advance genetic gain within an acceptable level of risk. Application for conditional registration must include a working plan. If approved, the specific deployment conditions will be determined by the Ministry of Forests.

Transferability For vegetative lots derived from untested or inadequately tested parents/clones, the transfer guidelines for natural stand provenances will apply.

For vegetative lots where the parent/clonal material has been tested, the transferability of the lot will be determined by the Ministry of Forests.

Rooted cutting production via the method described in this paper is more expensive than seedling production. The price of a Sitka spruce or western hemlock cutting is currently one-and-one-half to two times the price of a comparable seedling. Three factors contributing to this higher cost are: 1) cost of growing the stock plants, 2) labour for taking and setting the cuttings, and 3) higher risk in growing cutting crops.

The cost of growing the stock plants ensures that cuttings will always be more expensive to produce than seedlings. Some nurseries charge separately for growing the stock plants, while others include it in the cost of the cutting.

The process of taking and setting the cuttings is labour-intensive compared to seeding, which is normally mechanized in British Columbia forest nurseries. This expense is not likely to decrease significantly.

Rooting cuttings is a more variable and risky process than germinating seeds. The number of shippable plants in a cutting crop may also be lower than in a comparable seedling crop, because of the occurrence of multiple leaders, plagiotropism, and incomplete rooting in cuttings. This requires a larger oversow factor, which means more greenhouse space and hence higher costs.

The above discussion of cost from a nursery perspective does not include the cost of controlled-cross seed. Where crossing is necessary to create a specialty lot or to eliminate contamination or selfing, individual seed becomes expensive. However, this seed cost would become negligible if distributed across a large number of cuttings.

1+0 and 1+1 stocktypes In this notation, the first digit refers to the number of years grown in a container, the second refers to the number of years grown in a nursery bed. The two numbers added together give the age of the plant at lift.

adaxial Morphologically upper side of a branch (technically the side facing toward the axis).

basal cuttings (as opposed to tip cuttings) Cuttings from sections of branches or stems behind the tip; that is, without an apical meristem.

bulk-up When seeds of desired families or populations are in short supply, embryos or seedlings are clonally reproduced by rooting cuttings, tissue culture, grafting, or somatic embryogenesis. Clonal records are usually not kept.

compression wood The reaction wood in conifers that is normally formed on the underside of lateral branches, characterized by tracheids that are darker, thicker-walled, and rounder than normal xylem tracheids.

controlled pollination Application of pollen from a known source onto a selected receptive female flower, all other pollens being excluded.

first-order branch A branch that originates from the main stem or axis of the tree. A second-order branch originates from a first-order branch, and so on.

full-sib The offspring of a single tree in which the male parent is also in common.

hedging Pruning stock plants repeatedly to delay maturation.

IBA Indole-butyric-acid, a synthetic auxin commonly used in horticulture to stimulate rooting of cuttings.

NAA Napthalene-acetic-acid, a synthetic auxin commonly used in horticulture to stimulate rooting of cuttings.

open-pollinated family Progeny from a mating that is not controlled, so that there is one female parent but a mixture of pollen parents. The open-pollinated family is typically a mixture of full-sibs, half-sibs, and selfs.

orthotropic Having a vertical growth habit, as a leader.

photoperiod extension Extending the natural daylength with artificial lighting to affect the phenology of a plant.

plagiotropism (*plagios*=oblique, *tropos*=turning) A non-vertical growth habit, such as with a branch on an intact plant.

serial propagation The use of rooted cuttings themselves as stock plants to provide more cuttings.

somatic embryogenesis A process by which somatic cells are differentiated into somatic embryos.

stock plants Plants grown for the purpose of producing cutting material.

tip cuttings (as opposed to basal cuttings) Cuttings taken from the distal end of a branch, so that they have an apical meristem.

tissue culture A general term for aseptic cell, tissue, organ, and protoplast culture. Strictly, aseptic culture of callus tissue.

weevil resistance An attribute of having a resistance mechanism to reduce or eliminate attacks and damage from the weevil *Pissodes strobi*.

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